BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 10003

SUBJECT: Conceptual Design and Performance of Large Propulsion Stages Dry Launched Within a 50K Space Shuttle Payload Compartment
Case 105-3

DATE: October 1, 1969

FROM: A. S. Kiersarsky
M. H. Skeer

ABSTRACT

A large volume payload bay of a reusable earth to earth orbit shuttle capable of delivering 50K to low earth orbit could accommodate large dry launched propulsion stages that are suitable for lunar and synchronous orbit shuttle operations, and planetary spacecraft injection. Herein, various conceptual stage designs employing cryogenic, space storable, and nuclear propulsion systems are examined, and performance of the stages evaluated for a representative set of missions. It is presumed that the stages are fueled in orbit by succeeding space shuttle flights and in some cases, partially assembled in orbit.

Results of this study suggest that if available earth to earth orbit shuttle payload container dimensions are on the order of 60 ft length by 22 ft diameter (or as small as 15 ft diameter for partially assembled stages) shuttle launched stages would be capable of performing the spectrum of missions considered in the Integrated Space Flight Program.* This capability might enable the Integrated Program Plan to be achieved without use of Saturn V derivative launch vehicles.

A new series staging mode using cryogenic stages considered in this study appears attractive in association with direct delivery of large payloads to the lunar surface. These stages would be competitive with nuclear stages for planetary mission applications as well.

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*An Integrated Program of Space Utilization and Exploration for the Decade 1970 to 1980, NASA, July 16, 1969.

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MEMORANDUM FOR FILE

Introduction

Reusable earth to earth orbit shuttles capable of delivering up to 50K discretionary payload to earth orbit are being considered (Reference 1). These shuttles could support integrated earth orbit, lunar and planetary programs by delivering crew and assorted payloads including mission hardware, propulsion stages, and propellant to orbit where final hardware assembly or propellant transfer would occur (Reference 2). If all mission hardware could be launched in segments sized to space shuttle weight and volume envelopes, extensive missions could be performed without use of the Saturn V derivatives for earth orbit injection operations (Reference 3).

Large in-space propulsion stages are required to provide transportation for high earth orbit, cislunar and planetary missions. Currently a 300K, 33 ft diameter nuclear stage (Reference 2) which greatly exceeds the earth to earth orbit shuttle weight and volume constraints is being presumed to fulfill these requirements. If the set of missions could be performed with smaller or segmented stages dry launched within the earth to earth orbit shuttle Saturn V launch of in-space stages could be eliminated.

This memorandum considers stage configurations compatible with current shuttle launch weight and maximum volume envelopes. Designs are formulated for cryogenic, space storable, and nuclear stages and their respective performances are evaluated for a representative set of earth orbit, lunar and planetary missions. It is presumed that 1) stages are launched devoid of propellants and consumables, so that only stage dry weight has to be maintained within a 50K shuttle payload limit; and 2) the stages are fueled by propellant delivery on succeeding shuttle flights either from a "tank farm" in association with a space station, or directly by the shuttle. It is further assumed that assembly and checkout of large structures in orbit (remotely or with man in attendance) will be achievable in the projected time period, and that assembly of stages, where required, could be facilitated by temporary docking aids (i.e., docking collars, bumpers, and proximity sensing devices) which are jettisoned before stage activation so that no significant weight penalty would result from stage assembly in orbit.

Weight analysis of the various stage concepts and more detailed design considerations are included in an appendix.

Space Shuttle Payload Container Sizing

The tradeoff between space shuttle payload volume and gross weight may strongly impact shuttle payload compartment volume selection and therefore two payload volume envelopes are considered (Figure 1). The larger payload bay has a 60 ft length and is 22 ft in diameter. The volume is approximately equal to the SIVB stage, and is the largest payload bay section currently proposed for the various shuttle concepts (References 1 and 4). Enclosed volume is approximately 23,000 ft^3 which corresponds to a minimum payload density of 2.2 lbs/ft^3 for full payload/volume utilization. The alternate payload bay has a 60 ft length and 15 ft diameter, resulting in a reduced vehicle gross weight. This volume is, however, less desirable for present purposes because of the restrictions on payload. The enclosed volume is 10,600 ft^3 or 4.7 lbt/ft^3 with full payload volume utilization. A 1 ft clearance (i.e., reduction in diameter) is presumed for all stage designs, hence useful volume is reduced to 21,000 ft^3 and 9,000 ft^3 for 22 ft and 15 ft diameters, respectively. Available volume of the smaller payload compartment would limit transport of LH_2 to about 40,000 lbs.

Stage Design and Configurations

22 ft Cryogenic Stages - Stage designs and weight characteristics are summarized in Table 1. LO_2/LH_2 and LF_2/LH_2 cryogenic propellant combinations are considered with mixture ratios of 6:1 and 13:1, respectively. Specific impulse is estimated to be 460 sec in both cases. The 21 ft diameter configurations are sized in combination with 1) two 250K lbf extended bell engines and 2) a single 500K lbf aerospike engine (Figure 2). A feature of the 21 ft diameter stage is selection of a toroid propellant container in lieu of the more conventional elliptical tank designs because of the improved packaging efficiency, which results in an increased propellant weight of almost 20%. The aerospike engine enables propellant volume to be increased by 5% compared to the extended bell design, which is not deemed a significant advantage. Gross stage weight of the LO_2/LH_2 toroidal tank/extended bell stage design is 330K lbs and

the propellant fraction, λ (ratio of propellant weight to gross stage weight), is equal to .88. The stage is approximately 30% larger than the SIVB.

It is noted that since the stage is launched devoid of propellants launch loads which nominally govern design in unpressurized skirt areas are substantially reduced (i.e., by an order of magnitude). This enables significant weight savings to be achieved compared to more conventional stages launched with propellant and large payloads.

LF_2/LH_2 stages are shown in Figure 3. A substantial increase in gross weight is achieved by comparison to similar LO_2/LH_2 stage configurations. Gross stage weight is 539k lbs and 564k lbs for extended bell and aerospike designs, respectively, and λ is .92 in both cases. Since LF_2/LH_2 and LO_2/LH_2 stages are designed to the same set of volumetric constraints and equal engine thrust levels, dry stage weights are essentially the same in both configurations. The improved propellant fraction of the LF_2/LH_2 stage is solely a result of the increased propellant density.

<u>22 ft Diameter Space Storable Stage</u> - FLOX/CH_4 space storable propellants stages (Figure 4) afford a substantial increase in propellant weight for a fixed volume stage by comparison to cryogenics due to the relatively high propellant density. Configurations similar to the cryogenic stage result in stage gross weights of 906k and 933k for extended bell and aerospike configurations respectively. It is possible to store FLOX/Methane in a common bulkhead tank for extended durations because of the close thermal storage regimes of the propellants which includes a small ($\sim$10°F) common liquidous range. Additional packaging efficiency afforded by utilization of the common bulkhead configuration increases stage gross weight of the extended bell design to 964k lbs or 7%. Propellant fraction is approximately .94 in all cases and specific impulse is approximately 410 secs.

<u>15 ft Diameter Segmented LH_2/LO_2 Stage</u> - Figure 5 shows the configuration of a modularized stage comprised of an engine/oxidizer tank segment and two hydrogen tank segments utilizing the 15 ft diameter envelope. (Three space shuttles would be required to deliver the segments which are assembled in orbit.) Gross weight of the three segment design is 459k and the propellant fraction is .89.

22 ft Diameter Segmented Nuclear Stage - A nuclear stage comprised of a single module unit would greatly exceed space shuttle dry weight and volume envelopes. Consequently the stage is segmented into an engine module comprised of the Nerva engine and a small propellant tank, and propellant container modules. The latter may be varied in number to suit the scale of particular missions. Three, four, and five propellant module configurations are depicted in alternate cluster and linear tank arrangements in Figure 6. A 75k thrust Nerva engine is assumed in all cases. In the linear configurations propellant lines feed through successive tanks and into the small engine module tank. (Individual propellant modules might be jettisoned after depletion). Feed lines in the clustered tank feed directly into the engine module tank which essentially serves as a manifold in this configuration. Gross weight for the 3, 4, and 5 tank configurations are 317k, 410k, and 498k, respectively with corresponding propellant fractions of .71, .73, and .74.

Performance Capability of Selected Stage Designs

Large stages would be required to fulfill transportation requirements which include:

- low earth orbit to synchronous orbit shuttle,
- low earth orbit to lunar orbit shuttle,
- planetary injection, and
- transfer of hardware from low earth orbit to high elliptical orbit for spacecraft assembly.

In addition the cryogenic stages could be utilized for:*

- direct lunar landing and return to earth orbit,
- lunar orbit to surface logistics, and
- propulsive descent to the surface of Mars.

Lunar Shuttle Operations

The lunar shuttle mission provides a good basis for comparing the performance characteristics of the different stages (and is also representative of synchronous orbit missions since impulsive velocity requirements are quite similar). Table 2 shows a performance comparison of selected stage designs for a shuttle flight from low earth orbit to lunar orbit and return.

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*Nuclear stages would probably not be suitable in these cases because of rapid throttling requirements, and radiation hazards.

Maximum one-way discretionary payload and the required number of shuttle refueling flights are included. A 10k crew capsule is presumed to make the round trip. Performance of a 300k non-segmented nuclear shuttle is included as a basis for comparison.

The LO_2/LH_2 stage is not adequate for delivery of large payloads to a low altitude circular lunar orbit. (Use of the LO_2/LH_2 stage assembled from three tanks would increase this payload about 60% but this still does not provide sufficient payload). However, LF_2/LH_2 and $FLOX/CH_4$ stages are competitive with the nuclear stage and inherently afford greater operational simplicity because of the absence of radiation hazards. (Problems of toxic exhaust products which have limited use of fluorine based oxidizers in surface launch applications would be considerably eased for orbital operations.)

Performances of the segmented nuclear stages are slightly degraded by comparison to non-segmented stage because of the increased propellant tank area resulting in added meteoroid bumper weight.

A figure of merit which can give a useful measure of lunar shuttle efficiency is the ratio of discretionary payload to lunar orbit per space shuttle flight (lbs/sf). The nuclear stages have a ratio of 20,000 lbs/sf compared with 15,000 lbs/sf for the LF_2/LH_2 stage, 12,000 lbs/sf for the $FLOX/CH_4$ stage and from 1,000 to 4,000 lbs/sf for the LO_2/LH_2 stages. It is noted that the relative performance of the nuclear stage would be somewhat higher for round trip cargo missions. Figure 7 shows the performance of the selected stages for other combinations of payload.

Substantial improvement in performance can be derived from operation of two stages in series. As an example assume that propulsion module 1 boosts propulsion module 2 plus payload to high elliptical orbit, and returns. Propulsion module 2 then delivers the payload to lunar orbit (or directly to the surface) and returns to high elliptic earth orbit whereupon it is retrieved by propulsion module 1 which is refueled in low earth orbit. In this fashion two 330k LO_2/LH_2 could deliver 240k to lunar orbit (presuming a 10k crew capsule on each stage for stage recovery) or alternately deliver 60k to the lunar surface.* Comparisons of other stages for single stage and series launches are shown in Table 2. Note that series LF_2/LH_2 stages could land 175k

*If the second stage returned directly to low orbit (so that refueling of the first stage would not be required) 150k could be delivered to lunar orbit.

on the moon and $FLOX/CH_4$ stages could land 240k. The increase in performance efficiency of the LO_2/LH_2 stage measured in terms of payload per pound of fuel expended is increased by an order of magnitude as seen by the resulting increase in the figure of merit from 1,000 lbs/sf to 13,000 lbs/sf for lunar orbit operations. For the lunar landing this ratio is approximately 3,000 lbs/sf. LF_2/LH_2 and $FLOX/CH_4$ figures of merit for the landing mode are 6,000 lbs/sf and 5,000 lbs/sf, respectively.

Planetary Missions

A 1981 Venus Swingby Mars 40-day stopover mission is chosen to demonstrate the relative performance capabilities of selected stage designs for planetary missions. Discussion is limited to a comparison of the chemical stages with the baseline nuclear stage. Performances of the segmented nuclear stages are discussed in Reference 5 where numerous options dealing with the optimal number of propellant modules per mission and effects of module staging are treated in some depth.

The selected mission profiles make maximum use of reusable shuttles for launch and transfer of payload and propulsion segments to high elliptical orbit for planetary spacecraft assembly and injection. The baseline nuclear mission (Reference 6) is shown in Figure 8. The earth to earth orbit shuttle places fuel, crews, mission modules, and a small chemical propulsion stage into low earth orbit (Figure 9). The Saturn V is used to launch nuclear propulsion stages and planetary payload. The nuclear shuttle then transfers all the planetary system elements to a 24 hour ellipse for assembly and checkout. Between each trip from low earth orbit to the ellipse and return, the nuclear shuttle is refueled by the earth to earth orbit shuttle. Trans-Mars injection is performed by nuclear shuttle boost in which case the nuclear shuttle delivers itself to the parking ellipse, launches the planetary spacecraft and returns itself to low earth orbit. Mars orbit insertion into an elliptical capture orbit and departure are performed with a nuclear stage. The small chemical module returns the crew return module into an elliptical capture orbit. The crew is then returned to earth via the nuclear and earth to earth orbit shuttles.

The mission performed with chemical shuttles differs somewhat from the baseline in that no SV launch vehicles are utilized and the large propulsion stage is used for all maneuvers (versus the nuclear stage plus chemical module in the baseline mission). Mission configurations using only earth to earth orbit shuttles and reusable chemical stages are shown in Figures 10 to 12. Within slight variations three LO_2/LH_2 stages, two LF_2/LH_2 stages, or one $FLOX/CH_4$ stage are required for the same set of payloads to Mars. Table 3 shows a comparison of the Mars payload missions performed with the various propulsion stages. Significant factors included are the number of propulsion stages required, the number of stages recovered, the number of low orbit to elliptical orbit shuttle flights, and the number of earth to earth orbit shuttle flights for hardware and fueling. Note that all stages with the exception of one LO_2/LH_2 stage can be recovered, and that in terms of earth to earth orbit shuttle flights all chemical stages are quite similar. Total weight assembled in 24 hour parking orbit is increased by approximately 50% compared to the nuclear mission.

Observations and Conclusions

Results of this study suggest that if available space shuttle container dimensions are on the order of 60 ft length by 22 ft diameter (or as small as 15 ft diameter for partially assembled stages) shuttle launched stages would be capable of performing the spectrum of missions considered in the Integrated Space Flight Program.

LF_2/LH_2 and $FLOX/CH_4$ stages or LO_2/LH_2 stages in series are nearly competitive with nuclear stages for lunar orbit and synchronous orbit shuttle missions. Moreover in series operation these stages could land substantial payload on the lunar surface and return to earth orbit for reuse.

Any of the set of chemical stages could be used for planetary missions if extensive use of earth to earth orbit shuttles and low orbit to elliptical orbit transfer is made.

Concepts for segmented nuclear and chemical stages have been formulated which suggest that this approach could be implemented with development of appropriate connections and assembly aids. Performance of assembled stages would be somewhat degraded relative to single unit stages because of increased exposed surface area (i.e., additional meteoroid shielding) and plumbing, but these stages could still be attractive alternatives to utilization of SV derivative launch vehicles.

In conclusion the potential of the shuttle launched space propulsion stages has been demonstrated. However, feasibility can only be assessed by investigation of detailed design areas such as orbital fueling, assembly, maintenance, etc. which have not been incorporated in previous stage designs. No judgements are made herein with respect to the mission modes that have been considered compared to more conventional modes simply because a rather thorough evaluation of mission concepts, stage cost and shuttle cost tradeoffs is required. For example, when the costs of chemical stages and economy of shuttle launches are better understood it may develop that stage return on planetary missions does not warrant the complexity of this operation.

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M. H. Skeer

Attachments
- References
- Appendix
- Figures
- Tables

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TABLE 1. STAGE CONFIGURATIONS AND WEIGHT CHARACTERISTICS

STAGE	CONFIGURATION		NUMBER OF DRY LAUNCHES PER STAGE	PROPELLANT WEIGHT* (1000 LBS)	PROPELLANT RESIDUALS AND CONSUMABLES* (1000LBS)	STAGE DRY WEIGHT (1000 LBS)	GROSS STAGE WEIGHT (1000 LBS)	λ
LO_2/LH_2 60′ X 22′	TOROIDAL TANKS EXTENDED BELL		1	290	2.9	37.0	330	.88
	ELLIPSOIDAL TANK EXTENDED BELL		1	240	2.4	36.2	278	.865
	TOROIDAL TANK AEROSPIKE		1	305	3.0	38.3	346	.883
LO_2/LH_2 60′ X 15′	ELLIPSOIDAL TANK EXTENDED BELL		3	406	4.0	48.5	458	.885
LF_2/LH_2 60′ X 22′	TOROIDAL TANK EXTENDED BELL		1	495	4.9	38.5	539	.920
	TOROIDAL TANK AEROSPIKE		1	520	5.2	38.7	564	.923
$FLOX/CH_4$ 60′ X 22′	TOROIDAL TANK EXTENDED BELL	SEPARATE TANKS	1	855	8.5	42.9	906	.943
		COMMON BULKHEAD	1	911	9.1	43.8	964	.943
	TOROIDAL TANK AEROSPIKE	SEPARATE TANKS	1	880	8.8	43.7	932	.943
		COMMON BULKHEAD	1	925	9.2	44.6	979	.943
NUCLEAR 60′ X 22′	3 TANKS		4	225	2.2	92	319	.705
	4 TANKS		5	300	3.0	110	414	.726
	5 TANKS		6	370	3.7	128	502	.739

* LAUNCHED ON SUCCEEDING SHUTTLE FLIGHTS

NOTE: HEAVY LINES INDICATE STAGES SELECTED FOR SCALING ANALYSIS IN TABLE 2.

TABLE 2. LUNAR SHUTTLE PERFORMANCE – PAYLOADS TO LUNAR ORBIT AND SURFACE

STAGE	CONFIGURATION	STAGE WEIGHT (1000 LBS)	λ	NUMBER OF SHUTTLE FUELING FLIGHTS TO FILL STAGE	PAYLOAD TO LUNAR ORBIT (1000 LBS)		PAYLOAD TO LUNAR SURFACE (1000 LBS)
					SINGLE STAGE	TWO STAGES	TWO STAGES
BASELINE NUCLEAR	NON-SEGMENTED	300	.75	5	107	–	–
LO_2/LH_2	TOROIDAL TANK EXTENDED BELL	330	.88	6	16	240	60
LF_2/LH_2	TOROIDAL TANK EXTENDED BELL	539	.92	10	156	–	175
$FLOX/CH_4$	TOROIDAL TANK EXTENDED BELL COMMON BULKHEAD	964	.94	18	226	–	240
NUCLEAR	4 PROPELLANT MODULES	414	.73	6	127	–	–
NUCLEAR	5 PROPELLANT MODULES	502	.74	8	179	–	–

NOTES:

- PAYLOAD INCLUDES 10K CREW CAPSULE WHICH MAKES ROUND TRIP
- LUNAR LANDING SYSTEMS INCLUDED IN LANDED PAYLOAD WEIGHT
- THE TWO STAGE MISSION REQUIRES APPROXIMATELY 2.2 TO 3 TIMES THE NUMBER OF SHUTTLE FUELING FLIGHTS AS THE SINGLE STAGE MISSION DEPENDING ON STAGE SELECTION

TABLE 3. SUMMARY COMPARISON OF STAGE PERFORMANCE FOR 1981 MARS LANDING VENUS SWINGBY MISSION WITH SHUTTLE LAUNCHED CHEMICAL STAGES

STAGE	TOTAL WEIGHT ASSEMBLED IN 24 HR ELLIPTICAL PARKING ORBIT (1000 LBS)	TOTAL NUMBER OF INJECTION STAGES	STAGES* "RECOVERED"	SHUTTLE PAYLOAD FROM LOW ORBIT TO ELLIPTICAL ORBIT	NUMBER OF LOW ORBIT TO HIGH ORBIT TRANSFER SHUTTLE FLIGHTS†	NUMBER OF SATURN V DERIVATIVES	NUMBER OF EARTH TO EARTH ORBIT SHUTTLE FLIGHTS††		
							FUEL	OTHER	TOTAL
NUCLEAR**	815	2	2	260	4	2	9	9	18
LO_2/LH_2**	1255	3	2	131	6	0	53	9	62
LF_2/LH_2	1125◇	2◇	2	368	2	0	40	8	48
$FLOX/CH_4$	1230	1	1	575	2	0	48	7	55

FOOTNOTES: *STAGES RECOVERED BY 1) DEBOOST TO LOW EARTH ORBIT AFTER PLANETARY INJECTION AND 2) PROPULSIVE CAPTURE TO ELLIPTICAL ORBIT UPON EARTH RETURN (IT IS NOT SPECULATED UPON WHETHER STAGE RETURN IS WARRANTED IN THE LATTER CASE)

**EXCESS MARGIN IN NUCLEAR AND LO_2/LH_2 STAGES CAN EXTEND STAY TIME AT MARS TO 80 DAYS (WITH NO MARGIN REMAINING)

†CRYOGENIC STAGES DELIVER THEMSELVES TO ELLIPTICAL PARKING ORBIT AND ARE TOPPED BY SUCCEEDING SHUTTLE FLIGHTS. IT IS PRESUMED THE RADIATION HAZARD PRECLUDES THIS FOR THE NUCLEAR STAGE. TRANSFER SHUTTLE FLIGHTS DO NOT INCLUDE SELF PROPELLED STAGE DELIVERY.

††DOES NOT INCLUDE CREW RETURN FLIGHT FROM EARTH CAPTURE ORBIT UPON RETURN FROM PLANETARY MISSION.

◇ PLANETARY INJECTION STAGE OFF LOADED (SEE FIGURE 11)

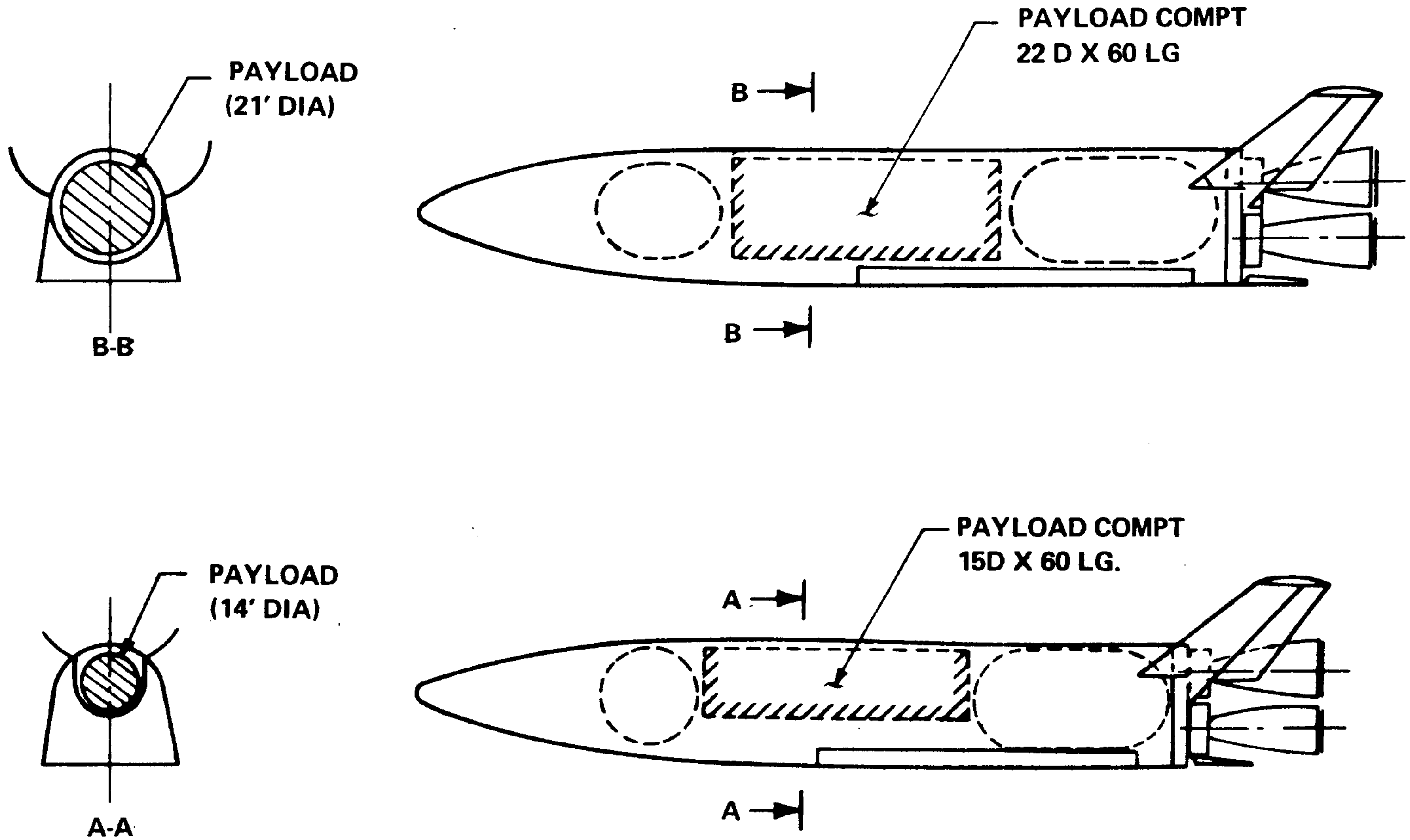
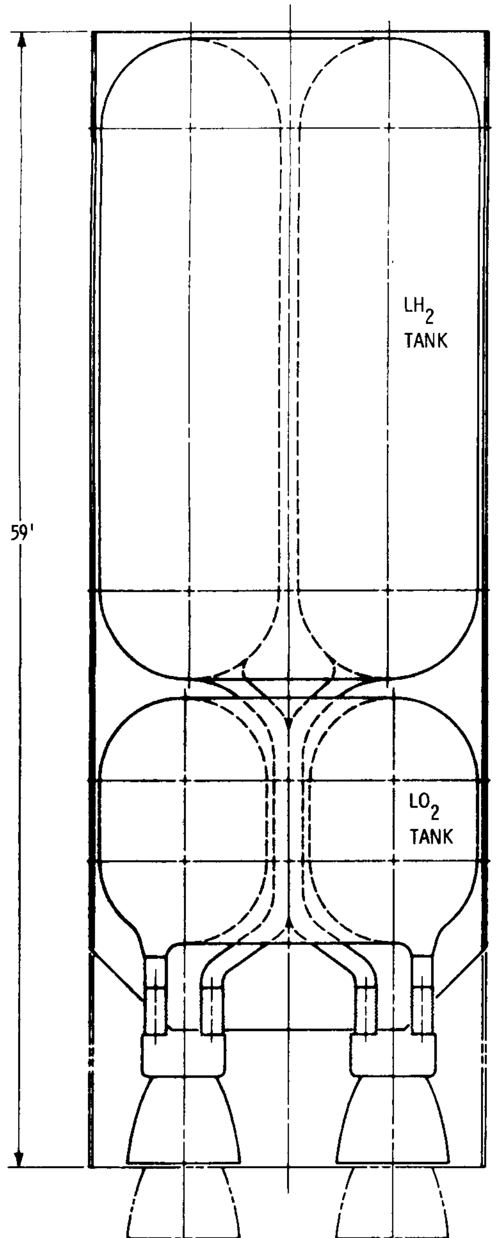
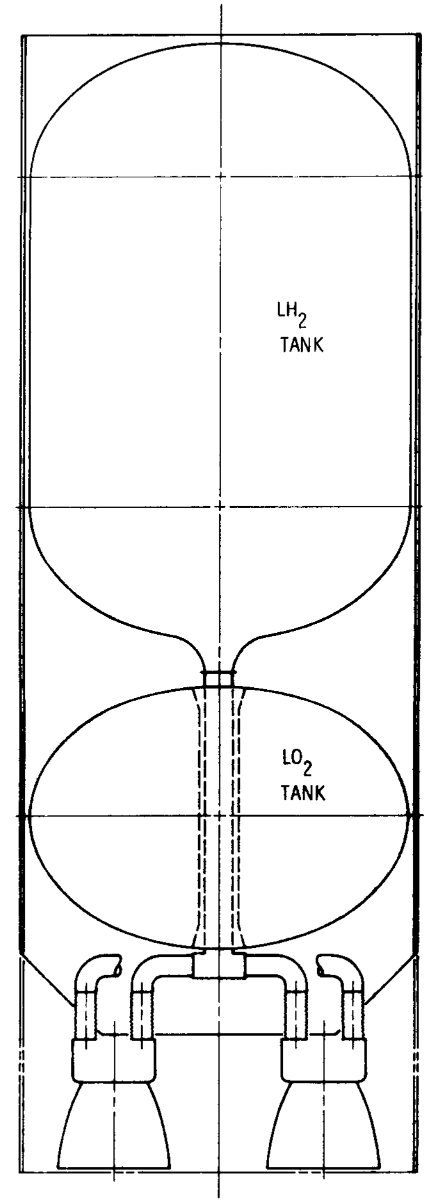


FIGURE 1 - PAYLOAD BAY ARRANGEMENT FOR 22 FT AND 15 FT DIAMETER EARTH TO EARTH ORBIT SHUTTLE CONFIGURATIONS



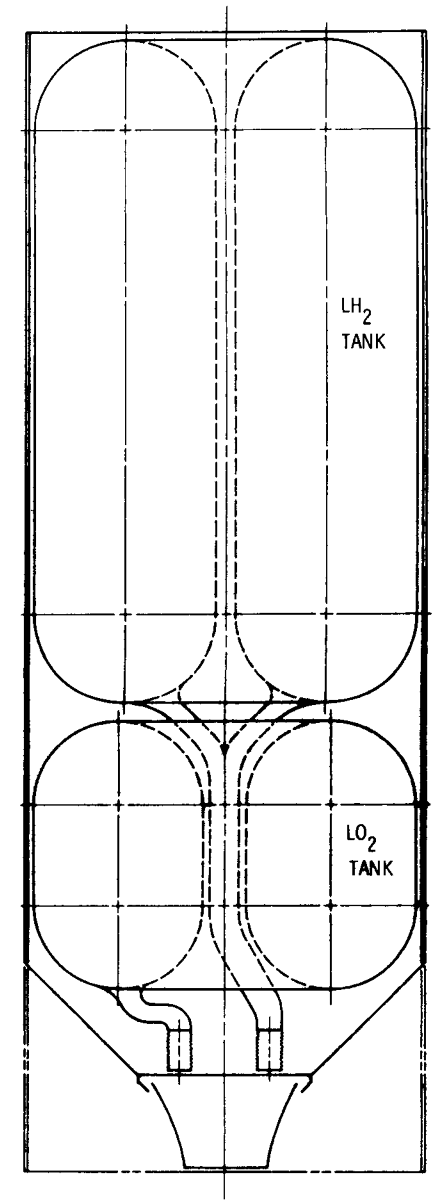
TOROIDAL TANKAGE CONFIGURATION
(2) 250K ENGINES (BELL TYPE)

FIGURE 2a



ELLIPTICAL HEAD TANKAGE CONFIGURATION
(2) 250K ENGINES (BELL TYPE)

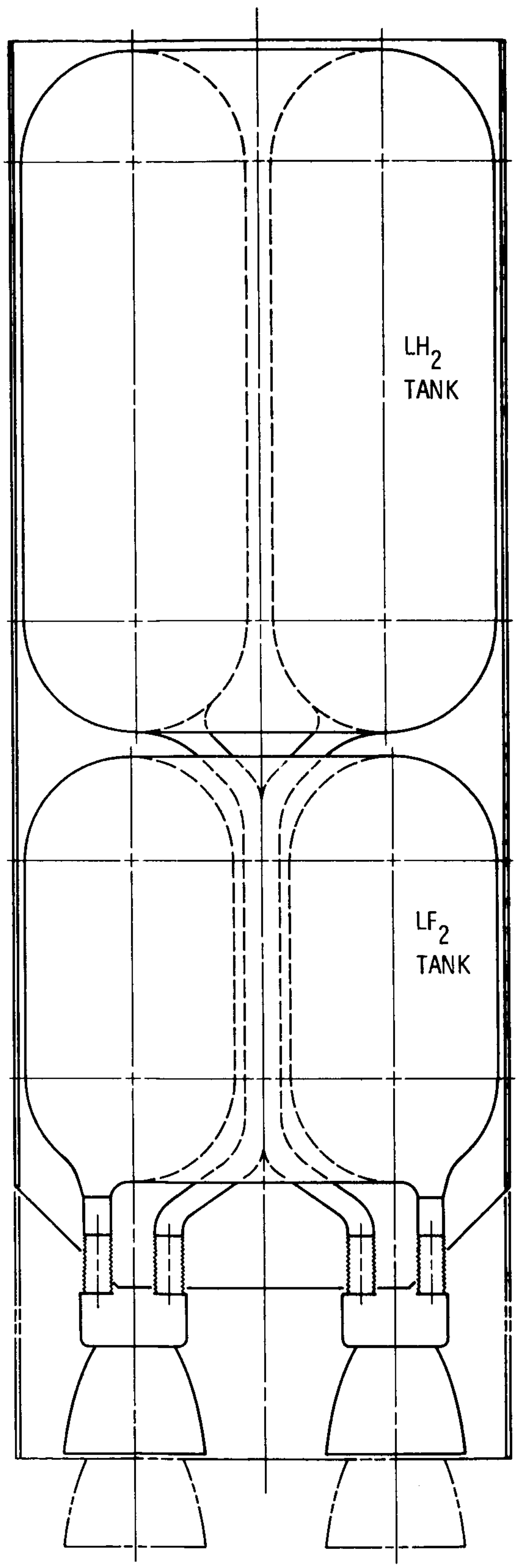
FIGURE 2b



TORIDAL TANKAGE CONFIGURATION
(1) 500K ENG. (AERO SPIKE TYPE)

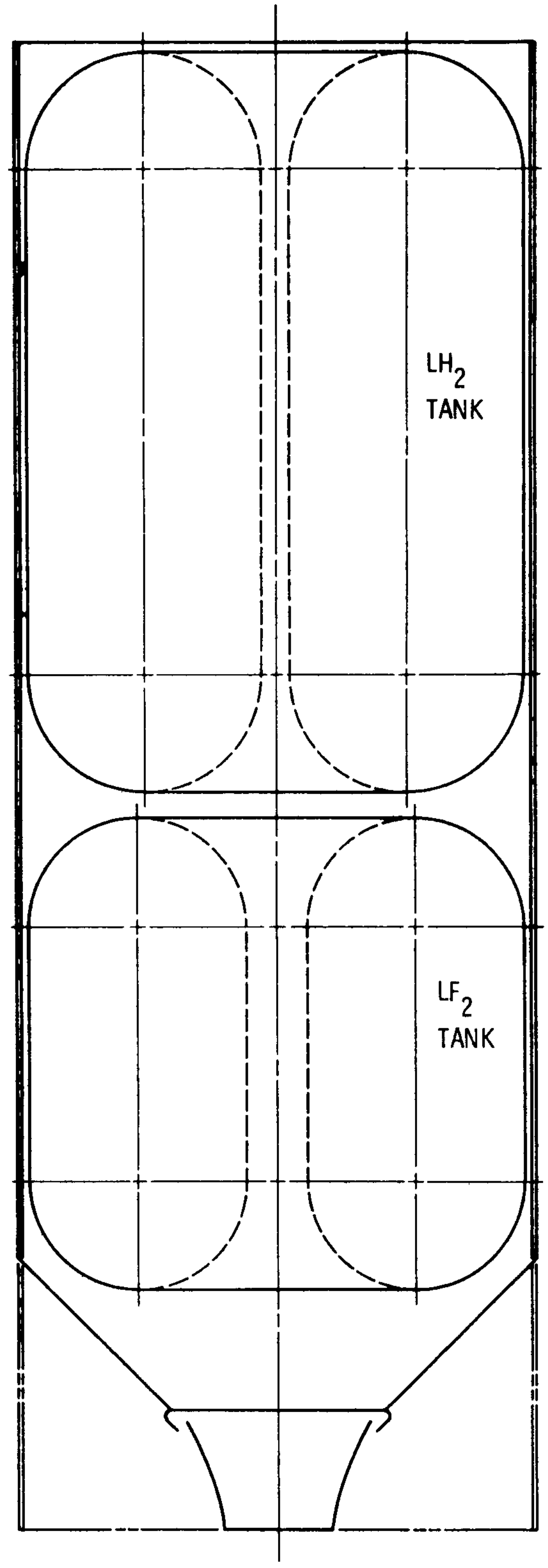
FIGURE 2c

FIGURE 2 - LO_2/LH_2 CONFIGURATIONS



TOROIDAL TANKAGE CONFIGURATION
(2) 250K ENGINES (BELL TYPE)

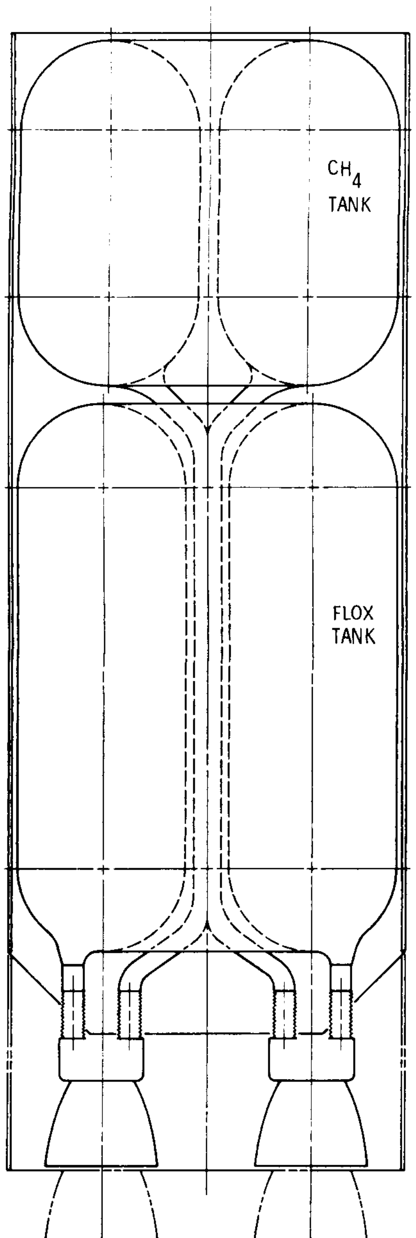
FIGURE 3a



TOROIDAL TANKAGE CONFIGURATION
(1) 500K ENG. (AERO SPIKE TYPE)

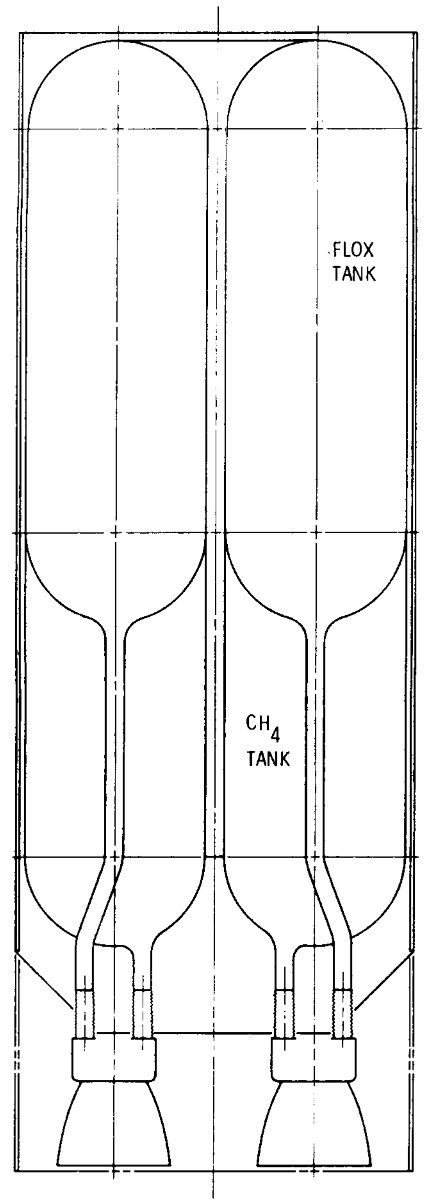
FIGURE 3b

FIGURE 3 - LF_2/LH_2 CONFIGURATIONS



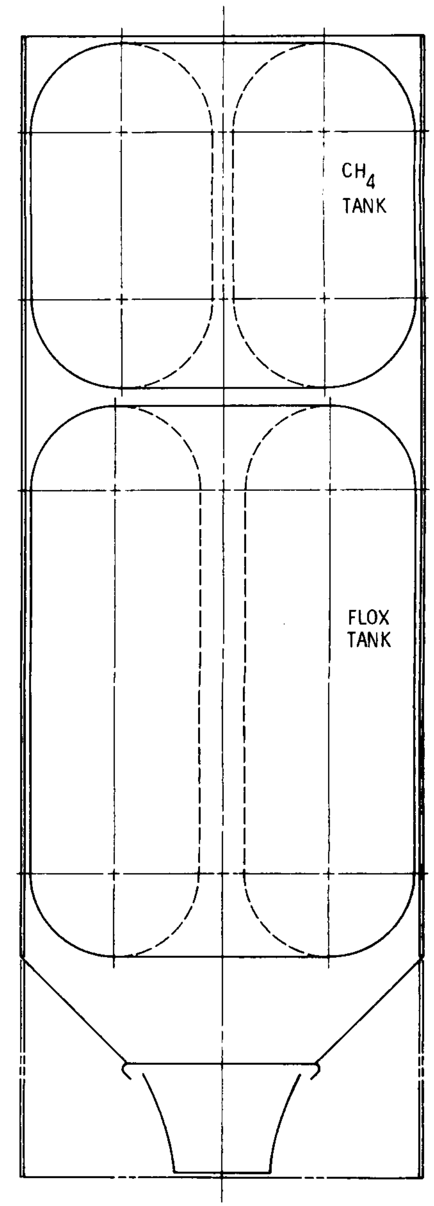
TOROIDAL TANKAGE CONFIGURATION
(3) 250K ENG. (BELL TYPE)

FIGURE 4a



FLOX/CH_4 CONFIGURATION
COMMON WALL TOROIDAL TANKAGE

FIGURE 4c



TOROIDAL TANKAGE CONFIGURATION
(1) 750K ENG. (AERO SPIKE TYPE)

FIGURE 4b

FIGURE 4 - FLOX/CH_4 CONFIGURATIONS

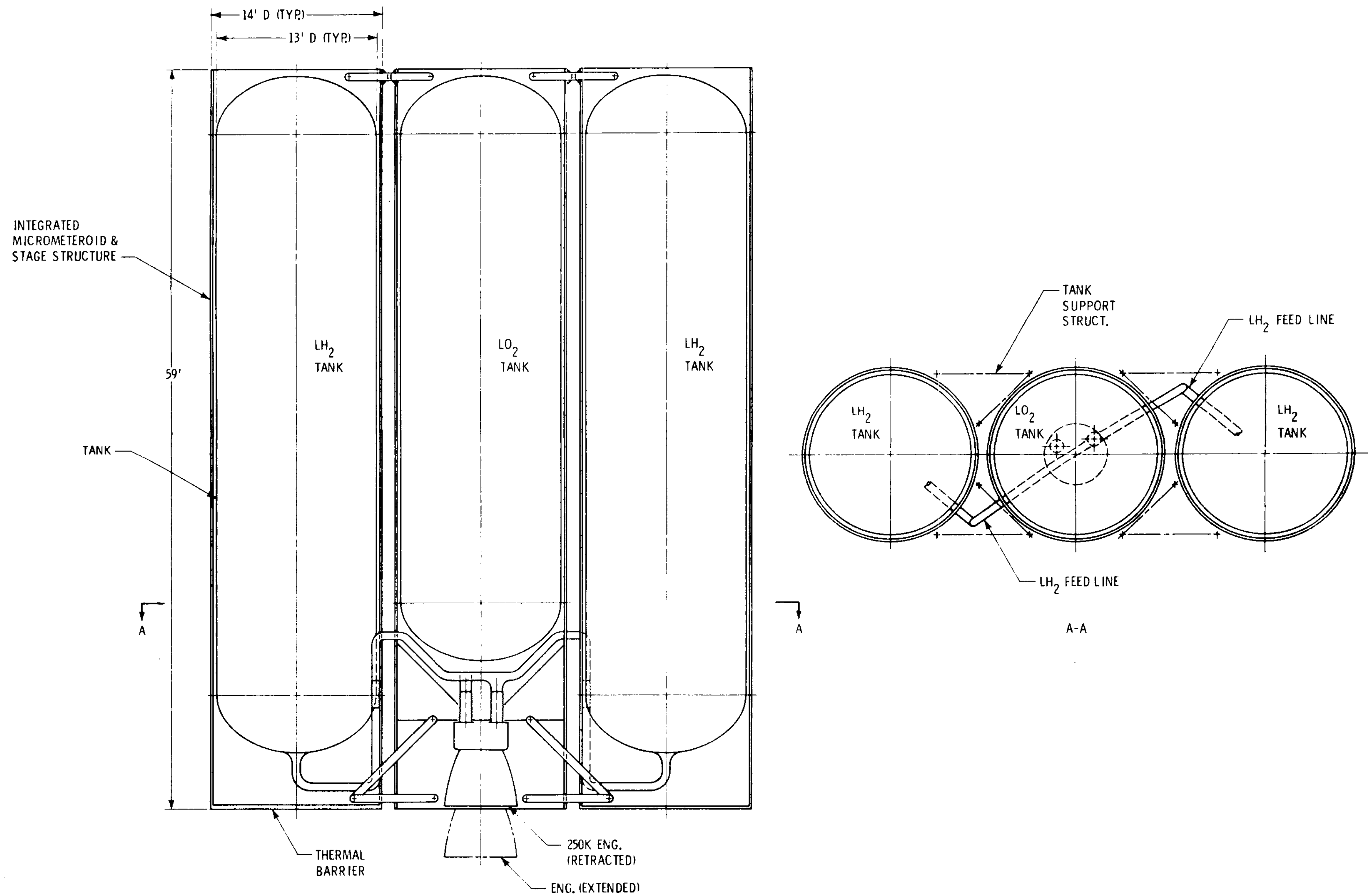


FIGURE 5 - LO_2/LH_2 CONFIGURATION
MULTIPLE TANK ARRANGEMENT

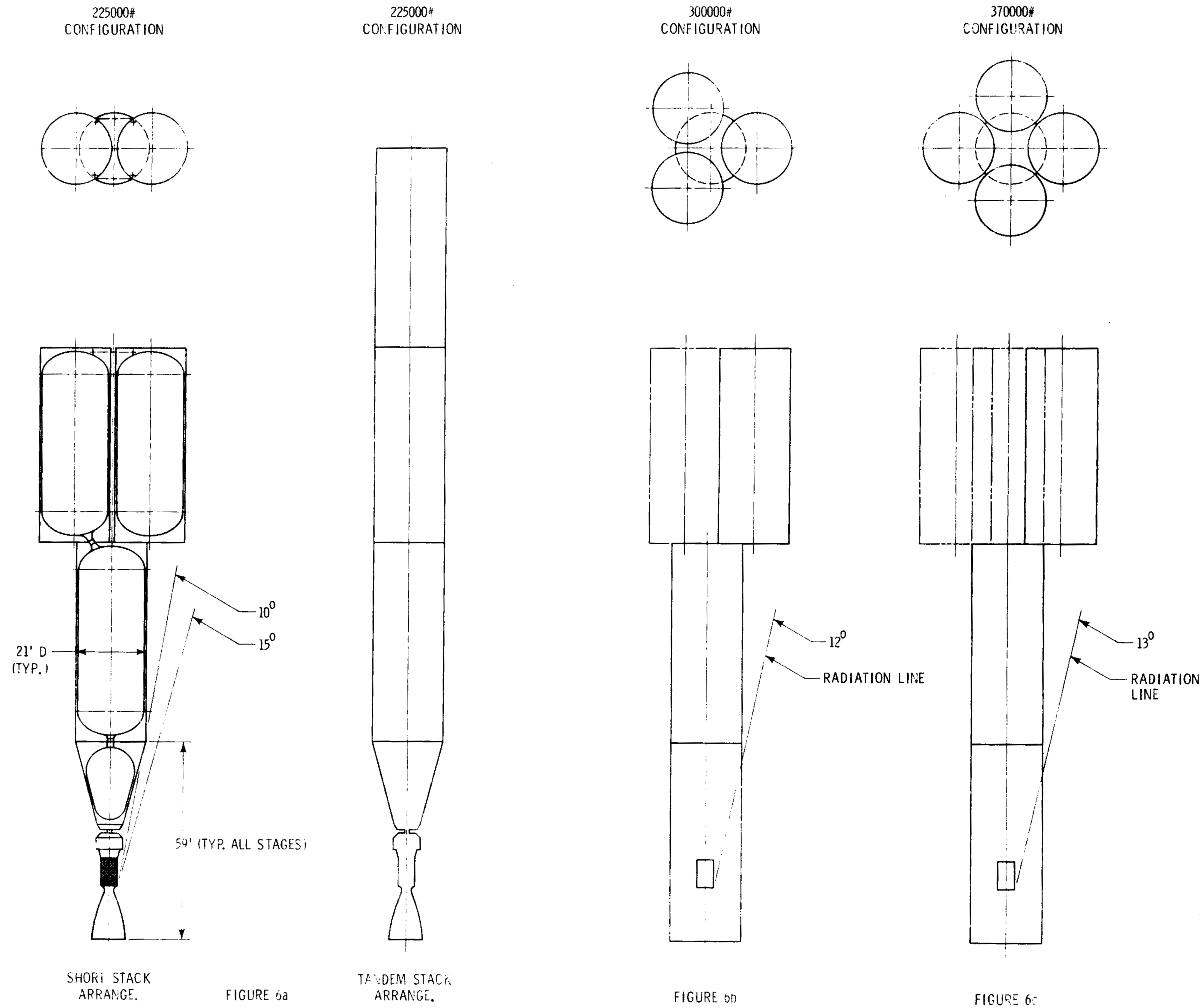


FIGURE 6 - NUCLEAR STAGE ARRANGEMENTS

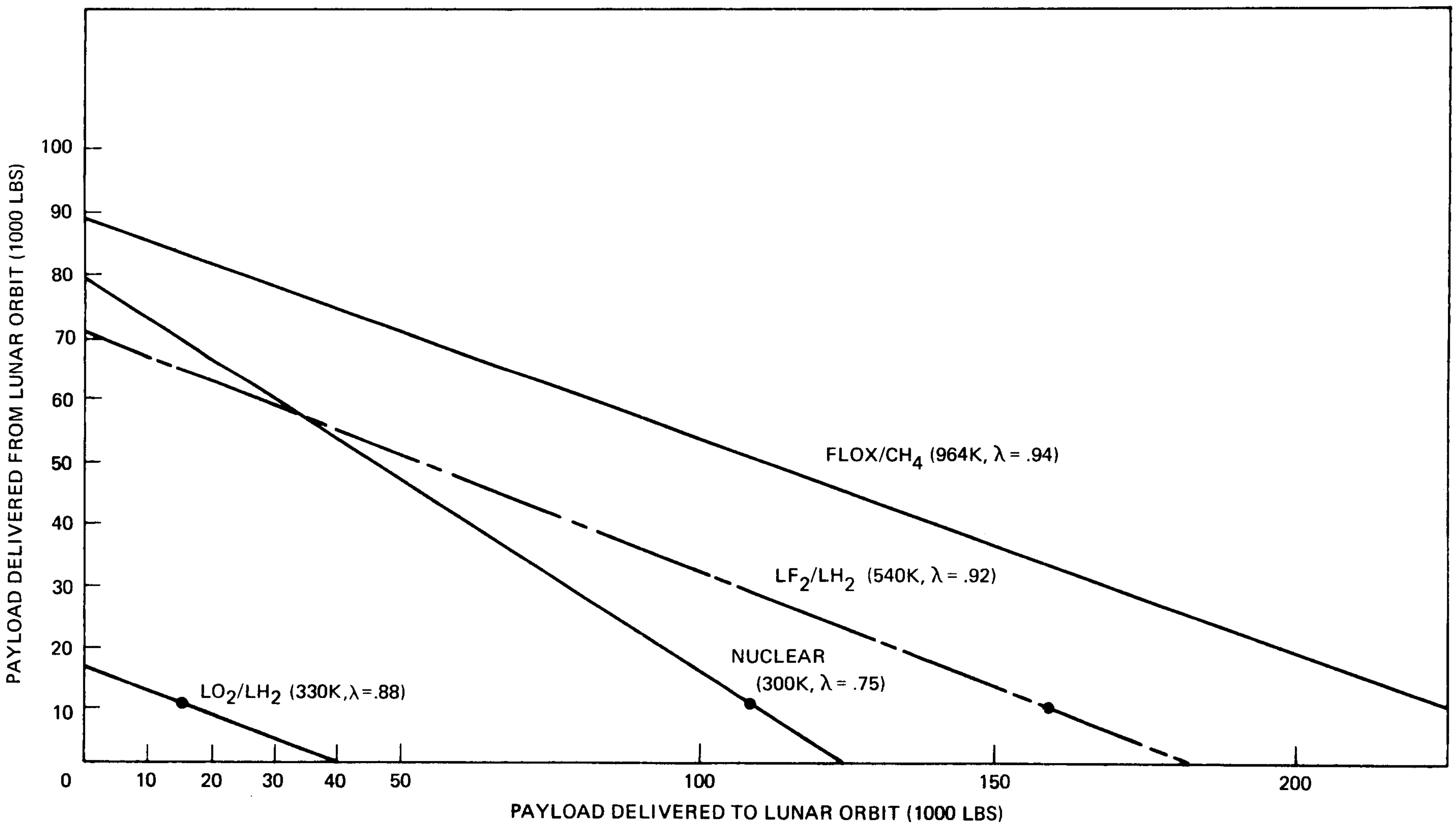
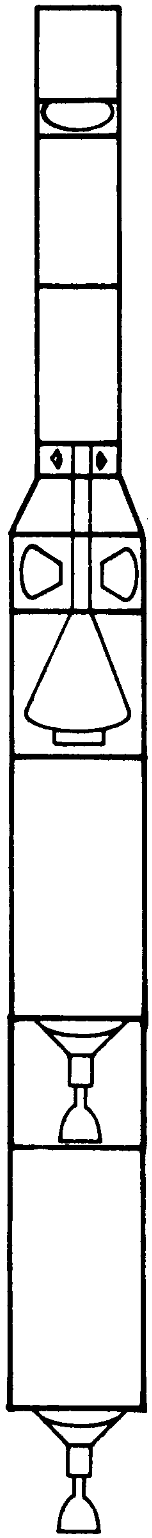


FIGURE 7 - COMPARISON OF IN SINGLE STAGE SPACE SHUTTLE FOR VARIOUS COMBINATIONS OF ONE WAY AND ROUND TRIP PAYLOADS TO LUNAR ORBIT



STAGE	WEIGHT (10^3 LBS)
PM (MANEUVERING, EARTH CAPTURE, RESCUE)	50
CREW RETURN MODULE	5
MISSION MODULE	50
MISSION MODULE (SPARE)	50
VENUS PROBES	10
RECEIVING FACILITY	15
6–MSSR'S	50
MEM + HANGAR	85
NUCLEAR STAGE	300
SHUTTLE BOOST STAGE	200
TOTAL WEIGHT	815

FIGURE 8. 1981 MARS LANDING VENUS SWINGBY MISSION WITH NUCLEAR STAGE

PLANETARY MISSION - SYSTEM PROFILE

1. SYSTEM ELEMENTS PLACED IN LOW ORBIT WITH E/O SHUTTLE AND SAT.-V
2. NUCLEAR SHUTTLE TRANSFER TO 24 HR ELLIPSE FOR ASS'Y AND CHECKOUT
3. NUCLEAR STAGE PERFORMS TMI AND MOI INTO HIGH ELLIPSE AT MARS
4. MEM AND MSSR LANDING OPERATIONS
5. TEI PERFORMED WITH CHEMICAL STAGES, WHICH ALSO RETRO CREW MODULES INTO HIGH ELLIPSE AT EARTH
6. NUCLEAR SHUTTLE AND E/O SHUTTLE RETURN CREW TO EARTH

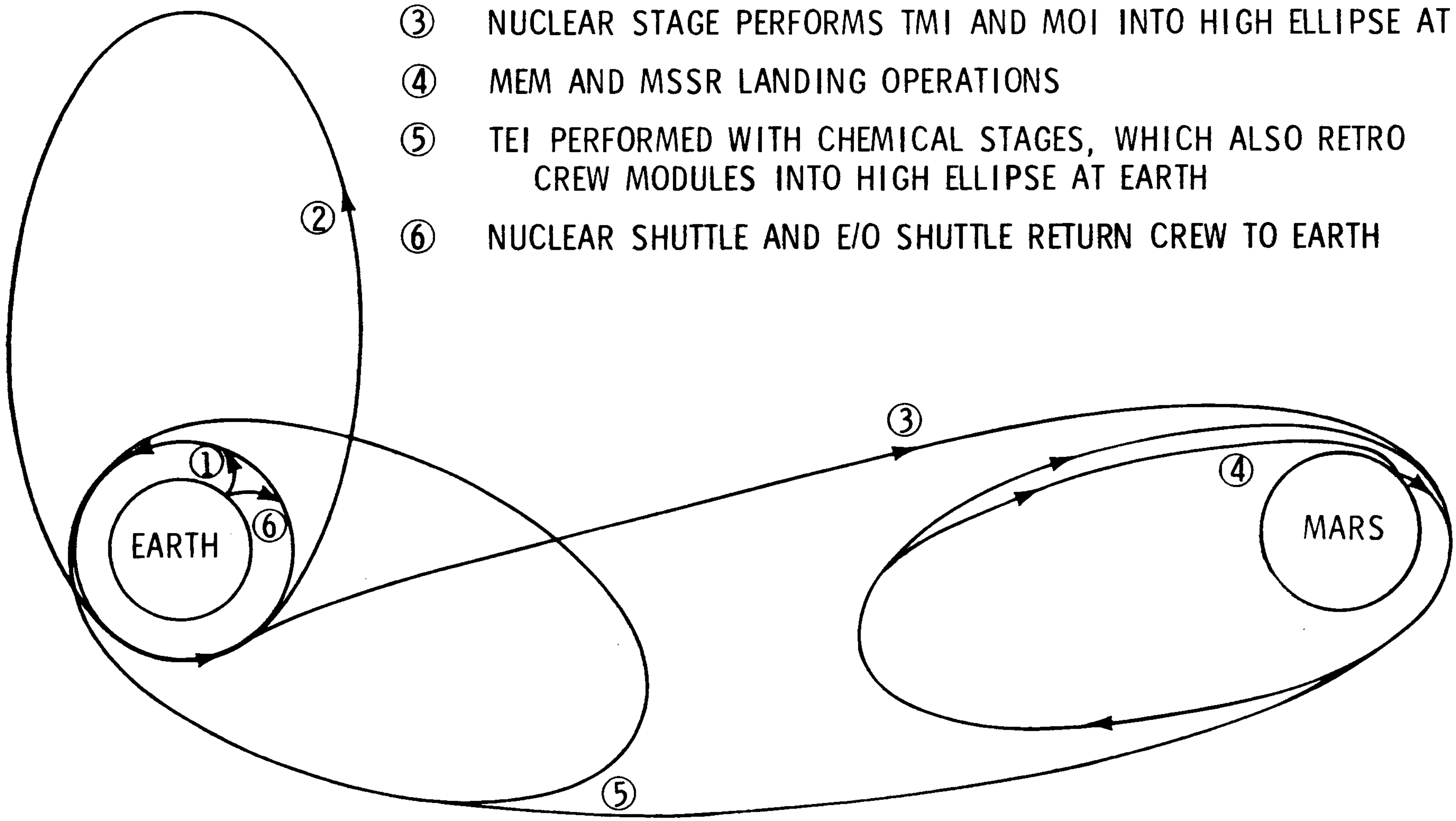
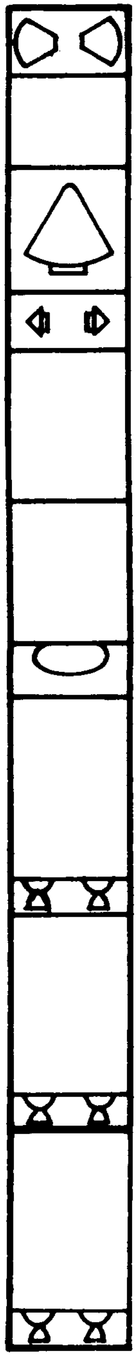


FIGURE 9 – BASELINE PLANETARY MISSION WITH NUCLEAR PROPULSION



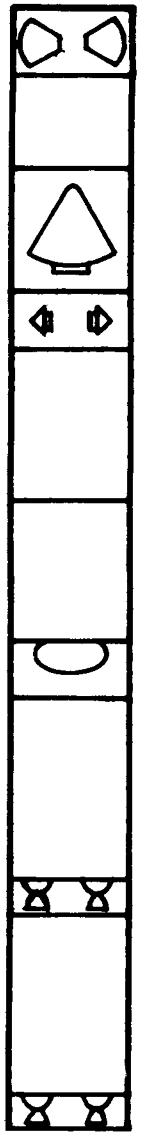
6 MSSR'S	50,000 LBS
RECEIVING LAB	15,000
MEM & HANGAR	85,000
VENUS PROBES	10,000
MISSION MODULE	50,000
MISSION MODULE	50,000
CREW RETURN MODULE	5,000
PROPULSION MODULE #3	330,000
PROPULSION MODULE #2	330,000
PROPULSION MODULE #1	330,000
TOTAL WEIGHT	1,255,000

(1) PROPULSION MODULES #1 AND #2 BOOST SPACECRAFT TO PLANETARY INJECTION VELOCITY SPEED. PROPULSION MODULE #1 RETURNS TO LOW EARTH ORBIT

(2) PROPULSION MODULE #2 COMPLETES EARTH ESCAPE ΔV, INITIATES MARS MANEUVER

(3) PROPULSION MODULE #3 COMPLETES MARS CAPTURE, BOOSTS SPACECRAFT TO MARS ESCAPE, DEBOOSTS ITSELF AND CREW RETURN MODULE INTO HIGHLY ELLIPTICAL EARTH ORBIT

FIGURE 10. 1981 MARS LANDING VENUS SWINGBY MISSION WITH SHUTTLE LAUNCHED LO_2/CH_2 CHEMICAL STAGES

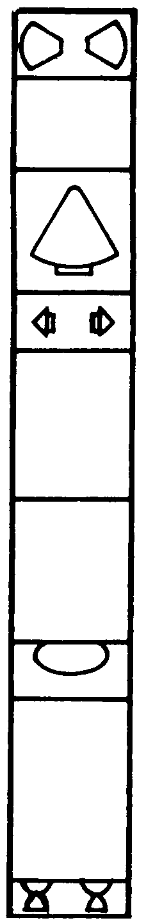


6 MSSR'S	50,000 LBS
RECEIVING LAB	15,000
MEM & HANGAR	85,000
VENUS PROBES	10,000
MISSION MODULE	50,000
MISSION MODULE	50,000
CREW RETURN MODULE	5,000
PROPULSION MODULE #2	540,000
PROPULSION MODULE #1	320,000 (OFF LOADED)
TOTAL WEIGHT	1,125,000

(1) PROPULSION MODULE #1 BOOST SPACECRAFT TO PLANETARY INJECTION VELOCITY AND RETURNS TO LOW EARTH ORBIT

(2) PROPULSION MODULE #2 PERFORMS MARS CAPTURE, BOOSTS SPACECRAFT TO MARS ESCAPE, DEBOOSTS ITSELF AND CREW RETURN MODULE INTO HIGHLY ELLIPTICAL EARTH ORBIT

FIGURE 11. 1981 MARS LANDING VENUS SWINGBY MISSION WITH SHUTTLE LAUNCHED LF_2/LO_2 CHEMICAL STAGES



6 MSSR'S	50,000 LBS	(1) PROPULSION MODULE BOOSTS SPACECRAFT TO PLANETARY INJECTION VELOCITY, PERFORMS MARS CAPTURE, BOOSTS SPACECRAFT TO MARS ESCAPE AND DE-BOOSTS ITSELF AND CREW RETURN INTO HIGHLY ELLIPTICAL EARTH ORBIT
RECEIVING LAB	15,000	
MEM & HANGAR	85,000	
VENUS PROBES	10,000	
MISSION MODULE	50,000	
MISSION MODULE	50,000	
CREW RETURN MODULE	5,000	
FLOX/CH_4 PROPULSION MODULE	964,000	
TOTAL WEIGHT	1,230,000	

FIGURE 12. 1981 MARS LANDING VENUS SWINGBY MISSION WITH SHUTTLE LAUNCHED FLOX/CH_4 CHEMICAL STAGES

APPENDIX

Introduction

The different configurations that were considered during this study and some of their design characteristics are described in this appendix.

A primary objective of this study was to determine the propellant capacity for varying tank configurations using different propellant combinations and engine types and to estimate the inert stage weight. There were five basic configurations and variations of each. Table IA is a list of the candidate configurations. Weight breakdowns of chemical and nuclear design point stages are shown in Tables IIA and IIIA, respectively. The stages are configured to accommodate long term operations in cislunar and transplanetary environments and are capable of multiple restart and reuse.

Guidelines

The potential capability of these configurations are based on the following guidelines:

- Stage configurations are sized for containment within the payload compartment of a space shuttle using the following compartment envelopes:
  - 22 ft dia by 60 ft long
  - 15 ft dia by 60 ft long
- Stage dry weight does not exceed 50,000 lbs for either payload envelope.
- Long term micrometeoroid protection is provided for all configurations.
- Insulation is included for long term propellant storage.
- Propellant combinations are slightly oxidizer rich for maximum volume utilization. The mixture ratios are as follows:
  - LO_2/LH_2 (M.R. 6:1)
  - LF_2/LH_2 (M.R. 13:1)
  - $FLOX/CH_4$ (M.R. 5.75:1)
  - LH_2 (nuclear stage)

- Engine data is derived from References 7-9.
  - For the bi-propellant stages two 250k, high pressure extendable bell engines and a single 500k thrust aerospike engine were compared.
  - For the nuclear stage configuration a 75k engine was used.
- To maximize propellant volume the following tankage configurations were considered:
  - Toroidal type tankage
  - Elliptically headed cylindrical tankage
- Propellant residual for both fuel and oxidizer was taken to be 1% of total propellant quantity.
- The following ullage requirements were used for the propellant tankage:
  - Fuel, 5%
  - Oxidizer, 3%
- Propulsion and auxiliary systems (not including main engines) weights for chemical stages were based on the SIVB stage (Reference 10) which is approximately the same size and dry weight as the design stages.

The propellant capacities and inert weights for each stage design are noted in the figures listed in Table IA. A 10% contingency for dry weight was assumed for all chemical stages. A more detailed weight breakdown of each configuration is given in Tables IIA and IIIA.

Chemical Stage Configurations

These stages were configured within the envelope limitations established for this study. For the large envelope, the stages varied only with different propellant combinations and engine types. The configuration using the smaller envelope required a multiple tank arrangement and was studied only for the LO_2/LH_2 propellant combination.

These stages consisted of an outer shell which functioned as the structural shell and meteoroid barrier. Within this shell the fuel and oxidizer tanks were configured as separate units supported by the outer shell using thermal insulation type supports. Additional insulation for long term storage was placed between the tanks and outer shell.

Nuclear Stage Configuration

The nuclear configuration consists of a propulsion unit module with additional tank modules added to increase the propellant capacity. The propulsion unit consists of a 75k nuclear engine supported from a truncated structural shell within which is supported a tear-drop shaped propellant tank. The outer structural shell provides meteoroid protection and also functions as the basic docking structure for additional tankage.

Sizing Effects

The shuttle payload compartment envelope had a direct influence on stage sizes, with stage diameters decreased by 1 ft in diameter to provide sufficient clearance for support, loading, and removal of the stages. This clearance limited the outer diameter of the different configurations to 21 ft diameter and 14 ft diameter.

Tankage diameter was reduced an additional 1 ft in diameter to allow space for insulation and the thickness of the outer meteoroid shell. As a result of these allowances the propellant tankage diameters were sized at 20 ft diameter and 13 ft diameter.

Some of the factors influencing propellant tank size with regard to length were as follows:

- The type of engine selected established the length allowance for the engines. The aerospike was shorter in length than the extendable bell type, and provided an increased tankage capacity of approximately 5%.

- Another factor influencing tankage length was the bellows length required for engine gimballing. The bellows length shown is approximately the same as that used for the J-2 engine on the SIVB.

- Other factors influencing tank volumes were the propellant feed lines, and intertank clearance.

Propellant Quantity

One of the objectives of this study was to maximize the propellant quantity and therefore both conventional elliptical ended cylindrical tanks and toroidal tanks were evaluated. In Figure 1 the toroidal tank versions using the extendable bell engine enabled a propellant weight increase of 20% for the LO_2/LH_2 propellant combination. As a result of this propellant difference the toroidal tank was selected for the other configurations with exception of the smaller multiple tank stage (Figure 2) and the nuclear configuration.

Stage Assembly

The larger 21 ft diameter stages were self contained except for the nuclear case. The smaller 14 ft diameter stage (Figure 3) required multiple tanks to provide a reasonable quantity. As shown in Figure 3 this version consisted of three tanks, two for LH_2 and one for LO_2 which also supported the engine systems.

The small stage design configuration will require in-orbit stage mating and joining of propellant fuel lines.

Structural Considerations

The stage designs are characterized in Figures 2 to 6. In all configurations propellant tanks are suspended from an outer shell which provides meteoroid protection and supports the stage during launch. Engines are also mounted directly to the outer shell structure. It is noted that the stage is launched devoid of propellants, so that launch loads which normally govern design in unpressurized skirt areas are substantially reduced (i.e., by an order of magnitude) and meteoroid and engine thrust loads govern. This enables significant weight savings to be achieved compared to more conventional stages launched with propellant and large payloads.

Meteoroid Protection

The meteoroid criterion chosen provides that there be a .99 probability of no punctures within 1 year (References 11 and 12) (or equivalently, .9 probability of no punctures in 10 years or .999 probability of not more than 1 puncture in 5 years). This assumption is significant since stage fractions, especially for the segmented nuclear stages, are quite sensitive to meteoroid shield weight. Outer shell thickness including meteoroid shielding is approximately 4 lbs/ft^2 ($\sim$.25 inch smear thickness.)

STAGE CONFIGURATIONS

TABLE IA

Stage	Configuration	
LO_2/LH_2	Toroidal Tankage Extended Bell Eng.	(Figure 2a)
(22' dia x 60' long)	Ellipsoidal Tankage Extended Bell Eng.	(Figure 2b)
	Toroidal Tankage Aerospike Eng.	(Figure 2c)
LF_2/LH_2	Toroidal Tankage Extended Bell Eng.	(Figure 3a)
(22' dia x 60' long)	Toroidal Tankage Aerospike Eng.	(Figure 3b)
$FLOX/CH_4$	Toroidal Tankage Extended Bell Eng. (Separate Tanks)	(Figure 4a)
(22' dia x 60' long)	Toroidal Tankage Extended Bell Eng. (Common Wall Tanks)	(Figure 4b)
	Toroidal Tankage Aerospike Eng.	(Figure 4c)
LO_2/LH_2 (15' dia x 60' long - 3 segments	Toroidal Tankage Extended Bell Eng.	(Figure 5)
Nuclear	3 Tanks	(Figure 6a)
22' dia x 60' long	4 Tanks	(Figure 6b)
(75k eng.)	5 Tanks	(Figure 6c)

TABLE IIA
WEIGHT BREAKDOWN
(CHEMICAL CONFIGURATION)

PROPELLANT	LO_2/LH_2			LO_2/LH_2	LF_2/LH_2		FLOX/CH_4		
FIGURE	FIG 2a	FIG 2b	Fig 2c	FIG 3	FIG 4a	FIG 4b	FIG 5a	FIG 5b	FIG 5c
TYPE	TOROIDAL TANKAGE EXTENDED BELL ENG	ELLIPSOIDAL TANKAGE EXTENDED BELL ENG	TOROIDAL TANKAGE AEROSPIKE ENGINE	ELLIPSOIDAL TANKAGE EXTENDED BELL ENG	TOROIDAL TANKAGE EXTENDED BELL ENG	TOROIDAL TANKAGE AEROSPIKE ENGINE	TOROIDAL TANKAGE EXTENDED BELL ENG	TOROIDAL TANKAGE AEROSPIKE ENGINE	TOROIDAL TANKAGE EXTENDED BELL ENG*
SHELL STRUCT. (INCLUDES MICRO & LOWER SKIRT)	13,450	13,450	13,450	23,400	13,450	13,450	13,450	13,450	13,450
PROPELLANT TANKAGE (INCLUDES INSUL & SUPPTS	7,870	7,284	8,180	12,140	8,340	8,500	9,000	9,400	9,500
ENGINES (INCLUDES THRUST STRUCTURE	7,850	7,850	8,750	4,250	8,750	8,800	11,700	12,000	11,850
**PROPULSION SYS (INCLUDES AUX EQUIPT., BELLOWS & LINES)	2,350	2,250	2,350	1,500	2,350	2,350	2,600	2,700	2,750
**AUX SYSTEMS (INCLUDES POWER CONTROL ETC.)	2,100	2,100	2,100	1,600	2,100	2,100	2,250	2,250	2,250
INTER TANK SUPPTS	----	----	----	1,200	----	----	----	----	----
ESTIMATED DRY	33,620	32,934	34,830	44,090	34,990	35,200	39,000	39,800	39,800
10% CONT.	3,362	3,293	3,483	4,409	3,499	3,520	3,900	3,980	3,980
TOTAL DRY WEIGHT #	36,982	36,227	38,313	48,499	38,489	38,720	42,900	43,780	43,780

*COMMON WALL TANKS

** ESTIMATED WEIGHTS BASED ON SIVB PROPULSION AND AUX SYSTEMS (8)

TABLE IIIA
WEIGHT BREAKDOWN
(NUCLEAR CONFIGURATION)

	Fig 6a (3) Tank	Fig 6b (4) Tank	Fig 6c (5) Tank
PROPULSION MODULE*	38,000	38,000	38,000
PROPELLANT TANKS	54,000	72,000	90,000
TOTAL WT	92,000	110,000	128,000

*PROPULSION MODULE

STRUCT. & TANKS	5,000
ENGINE & RAD. SHIELD	30,000
SYSTEMS	3,000
	38,000